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TITLE: PERMANENT-MAGNET SYNCHRONOUS MOTOR AND ITS ROTOR

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ABSTRACT:
PROBLEM TO BE SOLVED: To improve the stability of a permanent-magnet synchronous motor when the motor is operated at a high speed.

SOLUTION: A titanium ring 3 having a high specific strength and a relatively large coefficient of thermal expansion is used as the reinforcing and holding member of a permanent ring 2 and the projecting sections 3A on the internal surface of the ring 3 are directly engaged with a shaft 1 with initial interference between the sections 3A and shaft 1 so that coaxiality may be secured among the shaft 1, titanium ring 3, and permanent magnet ring 2 even when a permanent-magnet synchronous motor is operated. Therefore, the vibration of the motor can be suppressed when the motor is

operated at a high speed, because the rotor of the motor is not unbalanced in the peripheral direction, and a highly reliable operating stage can be obtained, because the centrifugal force which acts on the permanent magnets can be maintained.

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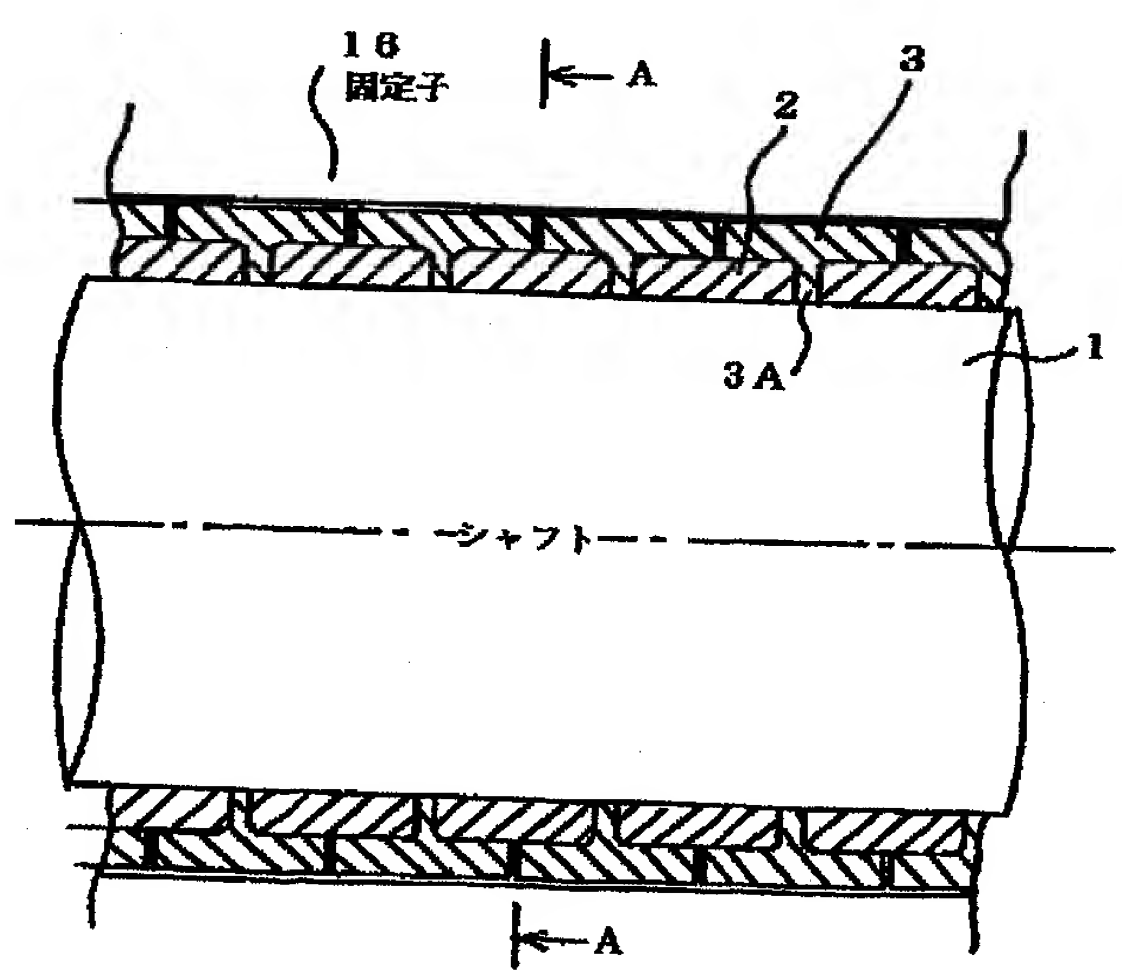
(54)【発明の名称】　永久磁石式同期電動機とその回転子

(57)【要約】
【課題】　永久磁石式同期電動機の高速運転時の安定性を向上させる。
【解決手段】　永久磁石リング２の補強、保持材として、比強度が高く、かつ熱膨張係数も比較的大きいチタンリング３を用い、その内周部の突部３Ａをシャフトとの間に初期締め代を持って直接系合させることにより、運転中においてもシャフト１とチタンリング３及び永久磁石リング２との同軸度を保てるようにした。これにより、高速運転中に回転子に周方向のアンバランスを生じないので、運転中の振動を抑制でき、また永久磁石に働く遠心力も保持できるので、安定した、信頼性の高い運転状態を得ることができる。



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【特許請求の範囲】

【請求項１】　シャフトと、
該シャフトの軸方向に並べて装着された複数のリング状永久磁石と、
該リング状永久磁石及びそれ自体の遠心力による伸びに見合う初期締め代を与えられてその内面の一部をなす直接系合面が前記シャフトに直接系合され、かつ前記直接系合面以外の内面が前記リング状永久磁石の外周面に系合されたところのチタンリングと、
を備えたことを特徴とする電動機の回転子。

【請求項２】　前記チタンリングの直接系合面は、当該チタンリングの軸方向中央部に設けられた内周面の突部の先端のなす面であることを特徴とする請求項１記載の電動機の回転子。

【請求項３】　前記チタンリングの直接系合面は、当該チタンリングの軸方向の一端に設けられた内周面の突部の先端のなす面であることを特徴とする請求項１記載の電動機の回転子。

【請求項４】　請求項１ないし３項の内の１つに記載の電動機の回転子を用いて構成した永久磁石式同期電動機。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、圧縮機等を駆動する超高速可変速電動機として使用される永久磁石式同期電動機とその回転子に関するものである。

【０００２】

【従来の技術】永久磁石を回転子に取り付けられた電動機は、小型かつ高性能の直流あるいは交流サーボモータとして多くの分野で利用されている。図３は、リング状永久磁石を有する回転子を備えた永久磁石式同期電動機の従来構造の一例を示す。同図に於て、電動機のシャフト１１にはリング状の永久磁石１２が装着され、それにカーボン繊維（以下ＣＦＲＰという）を巻き付けて形成されたＣＦＲＰリング１３とによって電動機ロータが構成されている。ロータはケーシング１５に保持された軸受１４によって支持されている。コイル１７を収納する固定子１６がケーシング１５に保持されている。本電動機はインバータ１８により給電される。

【０００３】本例のような永久磁石式同期電動機は、回転子を小さくでき、励磁電流が不要であるため効率を改善できる、等の長所がある。永久磁石１２としては、強磁束密度を確保するため、ネオジウム永久磁石等が用いられる。しかしながらこの磁石材料の破壊張力σamは約8kg/mm²と小さいので、比強度の大きい材料ＣＦＲＰ１３で巻き付け補強してある。カーボン繊維単独の引張強度は２００kg/mm²以上であるが、実際には繊維方向と遠心力のかかる方向が一致しないことやエポキシ樹脂を含

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なＣＦＲＰによる補強効果は次式で表される；

【数１】$tc=(\sigma m-\sigma am)tm/(\sigma ac-\sigma c)$

ここで、σm;永久磁石に働く遠心張力、σam;永久磁石の許容引張応力、σaciＣＦＲＰの許容引張応力、σc;ＣＦＲＰに働く遠心応力、tc;ＣＦＲＰリングの厚さ、tm;永久磁石リングの厚さである。この数値例が高橋勲「超高速モータの開発事例」、平成８年電気全国大会Ｓ．１８－３に示されているが、それによると、ロータ周速１９６ｍ／ｓで、およそσmが２９．２kg/mm²、σcが７．８kg/mm²である。今σamを８kg/mm²、安全を見てσａｃを５０kg/mm²とすると、（数１）からｔｃ/ｔｍは約2分の１となる。即ち、永久磁石に働く遠心張力σam＝８kg/mm²をこえていてもｔｃ／ｔm＝１／２程度の厚みのＣＦＲＰを巻き付けることにより、σc（＝７．８kg/mm²）＜θac（＝５０kg/mm²）の条件が成立し、永久磁石の破壊が防がれる。

【０００４】このような永久磁石式回転子の別の従来技術としては、特開平３－１１９５１号、特開平７－２８４２３７号等に開示されたものがある。前者の特開平３－１１９５１号に示された「回転電機の回転子」では、ロータのシャフトにリング状に取り付けられた永久磁石の外周に高張力のセラミックリングを嵌め込み、さらにその外周にチタン合金のリングを嵌め込んだ構造を提案している。また、特開平７－２８４２３号に示された「電動機の永久磁石付回転子」では、ロータのシャフトにリング状に取り付けられた永久磁石の外周を、非磁性体で構成したリング状の小幅の部材で、締り嵌めにより取り付けた構造を提案している。さらに上記リング状部材は、ロータの軸方向に沿って離れて複数個配置される。

【０００５】

【発明が解決しようとする課題】上記した図３の従来例の場合の半径方向の歪み量は、ＣＦＲＰの縦弾性係数を１００００kg/mm²とすると０．０００７８となる。従って直径１００mmのロータであれば、その半径方向の伸び量は０．０７８mmとなる。一方、このロータを周速１９６m/sで回転させるとそれは約３５０００ｒ．ｐ．ｍに相当するが、このように数万回転以上の高速でロータを回転させるとき、上記のようなＣＦＲＰの伸びに起因するロータ振動を招く恐れがある。

【０００６】また、上記した特開平３－１１９５１号によれば、セラミックリングの弾性係数は極めて大きいので、永久磁石は遠心力により半径方向に伸びて振動等を引き起こすことはない。また、特開平７－２８４２３７号によれば、やはりリング状部材の締り嵌めによって、高速回転時の半径方向の伸びを防いでいる。しかし、これらの技術はいずれも永久磁石を締め付ける形で永久磁石の変形を防止しており、締め付ける側、即ちセラミッ

い。またセラミックリングを用いるものは、電動機の大型化に伴い組立等が複雑になる。

【0007】本発明の目的は、高速運転回転時においても、永久磁石リング及び補強のためのリングと電動機シャフトとの同軸度を高度に維持でき、かつその組立も容易な構造の永久磁石式同期電動機とその回転子を提供することである。

【0008】

【課題を解決するための手段】上記の目的を達成するために、本発明は、シャフトと、該シャフトの軸方向に並べて装着された複数のリング状永久磁石と、該リング状永久磁石及びそれ自体の遠心力による伸びに見合う初期締め代を与えられてその内面の一部をなす直接系合面が前記シャフトに直接系合され、かつ前記直接系合面以外の内面が前記リング状永久磁石の該周面に系合されたところのチタンリングと、を備えたことを特徴とする電動機の回転子を開示する。

【0009】

【発明の実施の形態】以下、本発明の実施の形態を説明する。図1は、本発明になる永久磁石式同期電動機の回転子の構成を示す断面図、図2は、図1のA−A断面図である。これらの図において、回転子はシャフト1、永久磁石リング2、チタンリング3から構成され、また、固定子16にはコイル17が装着されている。永久磁石リング2は、軸方向に複数個配置され、それぞれのリング間には少しの間隔が設けられているが、このように複数のリングに分割するのは、電動機がある程度大きくなると、大きな幅の永久磁石リングを作成することができなくなるからである。チタンリング3も複数個に分割され、永久磁石リング2を保持するように装着される。各チタンリング3の内周には突部3Aが設けられており、その突部3Aは永久磁石リング2の間に配置され、突部3Aの内周部はシャフト1の表面に系合している。永久磁石リング2の断面形状は、図2のようにリング状であるが、磁気的には少なくともN、S極1対の磁極が形成されるように磁化されている。

【0010】上記の構成において、チタンリング3の突起部3Aの内周部、即ちシャフト表面との系合部の内径とシャフト外径寸法の関係は、永久磁石2の遠心力も考慮した遠心力伸びに見合う初期締め代（初期締め付け力）を持たせることのできるものとする。この締め代は、概略次式で表せる。

【数2】$\varepsilon \geqq (E_m \cdot t_m / E_t \cdot t_t)\,\varepsilon_m + \varepsilon_t$

$\Delta d = \varepsilon D$

ここで、Em;永久磁石リングの縦弾性係数、Et;チタンリングの縦弾性係数、εm;永久磁石リングの遠心力による仮想歪み、εt;チタンリングの遠心力による歪み、D；チタンリング径、Δd；チタンリングの初期締め

2に働く遠心力を受け持つための締め代に相当し、右辺第二項は、チタンリング3自身の遠心力伸びを受け持つための締め代に相当している。両者の和以上の初期締め付け力を与えることにより、回転中にチタンリング3がシャフト1から離れることがなくなる。かつ永久磁石リング2も、チタンリング3に系合されることによって半径方向に拘束されるので、シャフト1との同軸度が保たれる。このようにすることによって、運転中のチタンリング3とシャフト1の同軸度を保つことができるので、運転中のアンバランスの発生をなくすことができる。

【0011】図1の回転子の組立に当たっては、シャフト1上に1つの永久磁石リング2を嵌め込むと、次に1つのチタンリング3を嵌め込む。このとき先に嵌め込んだ永久磁石リングと、チタンリングの突起部の片端との間の内周面とが系合し、かつ突起部内周面がシャフトに系合するように、前記の初期締め代△dを与えてチタンリングを嵌め込む。次に、今嵌め込んだチタンリングの突起部ともう1つの端部との間の内周面に次の永久磁石リングが系合するように当該永久磁石リングを嵌め込む。以下同様の作業を繰り返すことで回転子に永久磁石及びチタンリングを取り付けることができるが、このとき永久磁石リングは引張限界応力が小さいこと、焼きバメ作業時のチタンリングと永久磁石リングの組み込み作業を容易にし、すばやく行うために永久磁石リングのシャフトへの初期締め代は不要、即ち0として作業を行う。

【0012】本実施の形態によれば、チタンリングをその内周面の突起部で直接シャフト表面に十分な締め代を与えて系合させるから、チタンリング自体が高速回転時に遠心力で半径方向に伸びることはなく、かつ永久磁石もチタンリングに系合され保持されることにより、遠心力で伸びることも防がれ、高速運転の振動を確実に抑圧できる。

【0013】図4は、本発明になる永久磁石付回転子の別の構成例を示すもので、チタンリングの形状を変えたものである。同図は図1と同じく回転子の軸を含む断面図で、かつその上半分の一部分だけを図示している。シャフト1の外周に永久磁石リング2が適当な間隔でもって複数個取り付けられているのは図1の構成と同じであるが、チタンリング40は、同図の断面でみると図1のものがいわばT型であったのに対し、L型形状をなしている。即ち、リングの一端の内周部に突起部40Aが設けられ、これが永久磁石リングの間に挿入され、シャフト1と直接系合するようになっている。この構成でも、突起部40Aの内周面の径を（数2）で説明した値に設定して適当な締め代を与えることによって、図1と同様な効果がある。さらに図4の場合には、チタンリング40の成型が容易になり、かつシャフトへの取り付けもよ

さらに別の構成例を示すもので、図1の構成の変形例である。即ち、永久磁石2は4個づつ、軸方向に隣接して配置され、4個おきの間に、その断面がT字型のチタンリング50の突起部50Aが挿入され、その内周面でシャフト1の表面と系合する構成である。このような構成は、隣接配置される永久磁石の個数を2、3、・・・と任意にとることも可能で、これを多くとるほどチタンリングの軸方向幅が長くなり、シャフトへの取り付け作業工程の減少に効果がある。但し軸方向幅の増大はチタン内での渦電流損失の増大を招き、またシャフトとの直接系合面の面積が減少する。従ってこれらのトレードオフで適当な永久磁石の個数を選定する必要がある。

【0015】図6は、本発明になる永久磁石付回転子のさらに別の構成例を示すもので、図4の構成の変形例である。即ち、永久磁石2は4個づつ、軸方向に隣接して配置され、4個おきの間に、その断面がL字型のチタンリング60の突起部60Aが挿入され、その内周面でシャフト1の表面と系合する構成である。この場合も、隣接配置される永久磁石の個数を適当に選ぶことで、シャフトへの取り付け工程削減を行うことができる。また、図5、6のいずれの場合も、突起部の付け根には、高速回転時の永久磁石及びチタンリング自体の遠心力による伸びにより大きな曲げモーメントがかかる。曲げモーメントは、チタンリングの軸方向幅が大きいほど大きくなるから、この点も考慮した設計が必要である。

【0016】

【発明の効果】本発明によれば、高速運転中に回転子にアンバランスを生じないので、運転中の振動を抑制でき、また永久磁石に働く遠心力も保持できるので、安定した、信頼性の高い運転状態を得ることができる。

【図面の簡単な説明】

【図1】本発明になる永久磁石付回転子の構成例を示す図である。

【図2】図1の回転子のA－A断面図である。

【図3】従来の永久磁石式同期電動機の構成例を示す図である。

【図4】本発明になる永久磁石付回転子の別の構成例を示す図である。

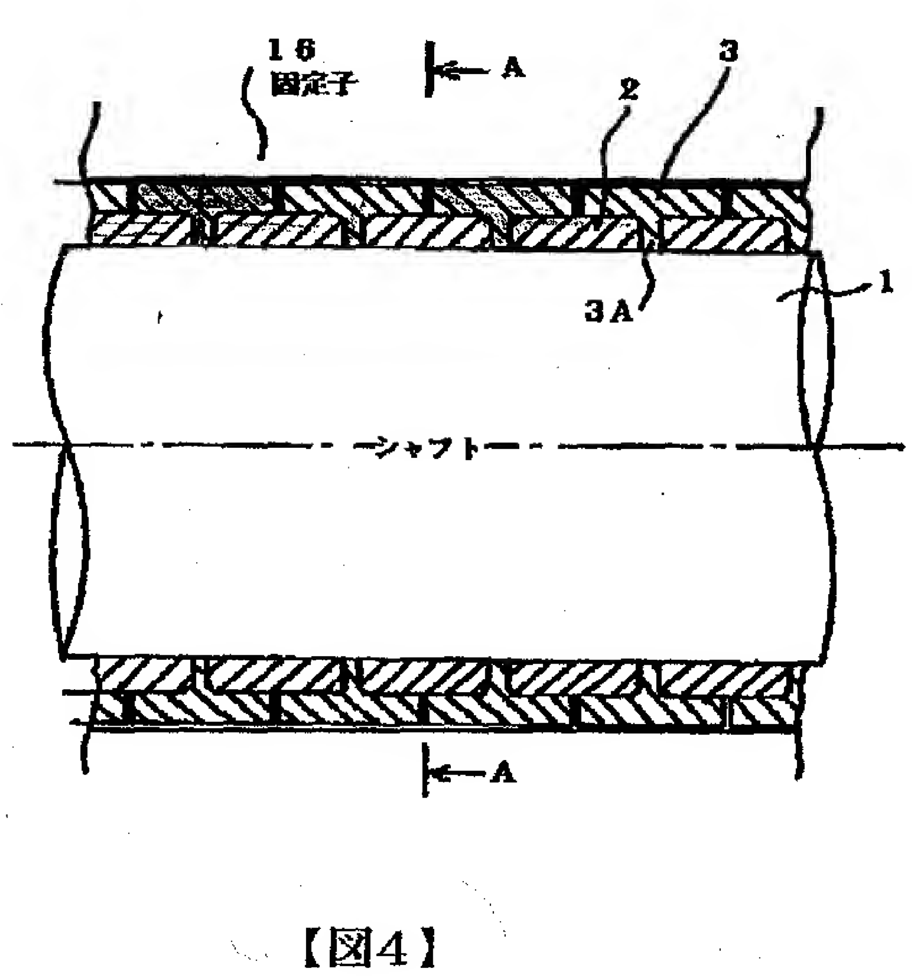
【図5】本発明になる永久磁石付回転子のさらに別の構成例を示す図である。

【図6】本発明になる永久磁石付回転子のさらに別の構成例を示す図である。

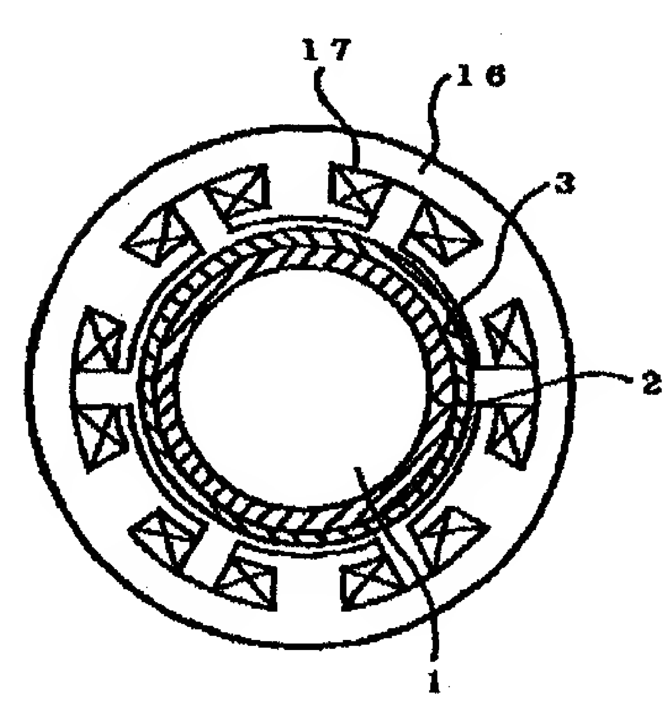
【符号の説明】

1　シャフト
2　永久磁石リング
3、40、50、60　チタンリング
3A、40A、50A、60A　突部
16　固定子鉄心
17　コイル

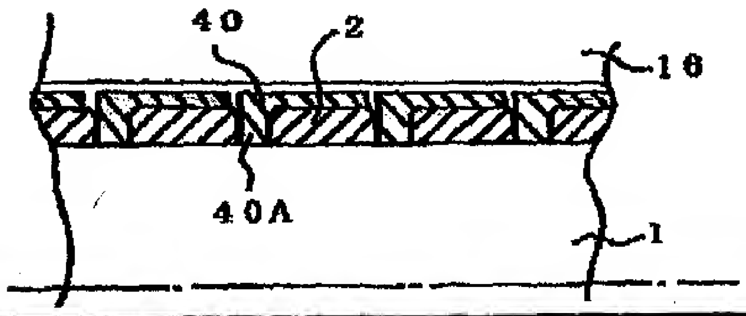
【図1】



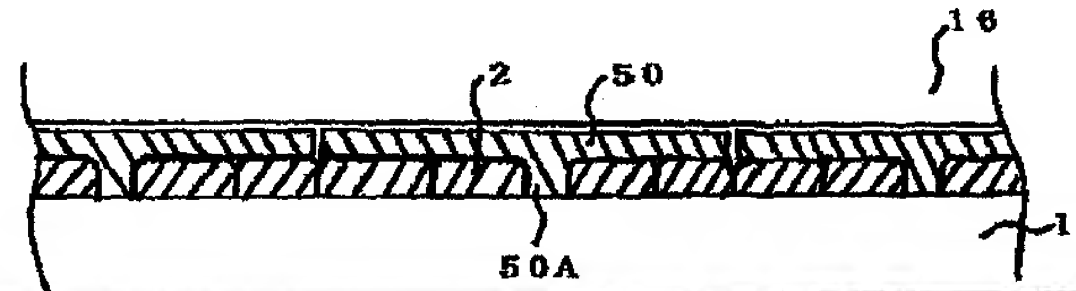
【図2】



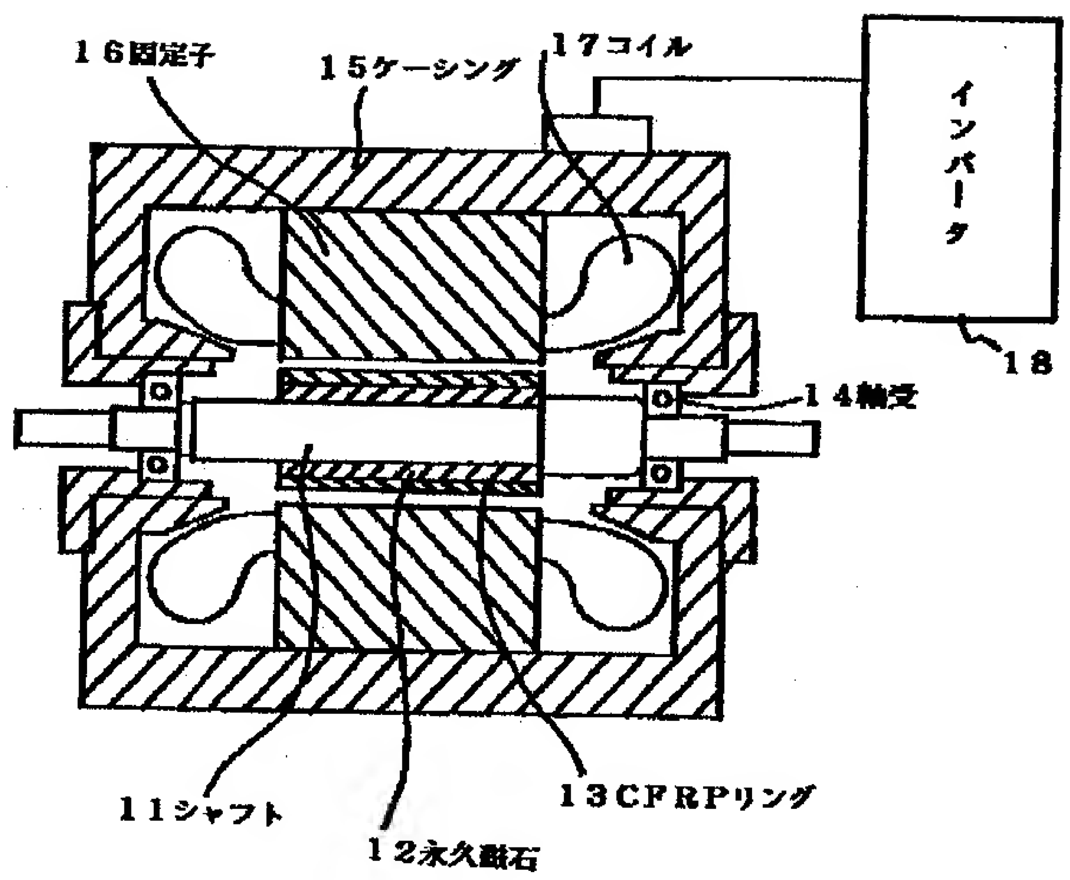
【図4】



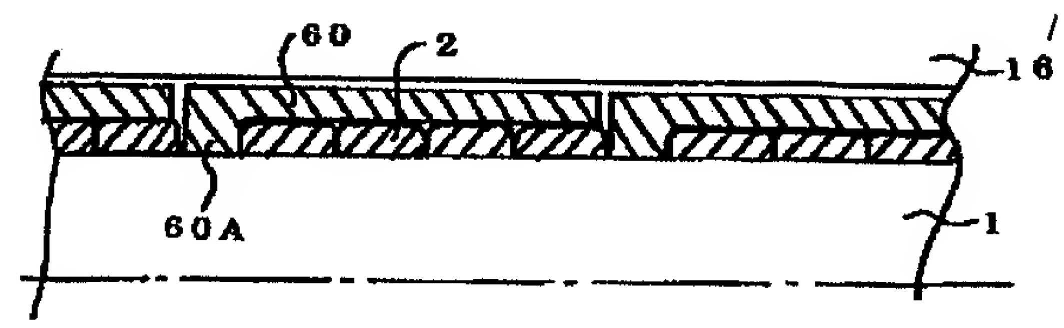
【図5】



【図3】



【図6】



フロントページの続き

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] this invention relates to the permanent magnet formula synchronous motor used as a ultra high-speed adjustable-speed motor which drives a compressor etc., and its rotator.
[0002]
[Description of the Prior Art] The motor in which the permanent magnet was attached by the rotator is used in many fields as a small and highly efficient direct current or an AC servo motor. Drawing 3 shows an example of the conventional structure of the permanent magnet formula synchronous motor equipped with the rotator which has a ring-like permanent magnet. In this drawing, the shaft 11 of a motor is equipped with the ring-like permanent magnet 12, and motor Rota is constituted by the CFRP ring 13 which twisted the carbon fiber (it is called Following CFRP) around it, and was formed in it. Rota is supported by the bearing 14 held at casing 15. The stator 16 which contains a coil 17 is held at casing 15. Electric power is supplied to this motor by the inverter 18.
[0003] A permanent magnet formula synchronous motor like this example can make a rotator small, and since the exciting current is unnecessary, it has the advantage of ** in which efficiency is improvable. As a permanent magnet 12, in order to secure strong flux density, a neodium permanent magnet etc. is used. However, since destructive tension sigmaam of this magnet material is as small as 2 about 8kg/mm, it twists and it has been reinforced with the large material CFRP 13 of specific strength. Although carbon-fiber independent tensile strength is two or more [200kg //mm], since a grain direction and the direction which a centrifugal force's requires not being in agreement in fact, and the epoxy resin are infiltrated, CFRP in the state where the rotator was equipped has the tensile strength of two or more / dozens ofkg //mm]. The reinforcement effect by such CFRP is expressed with the following formula.;
[Equation 1] Thickness of the centrifugal tension and the permissible tensile stress of a sigmaam; permanent magnet which work to a sigmam; permanent magnet tc=(sigma m-sigma am) tm / (sigmaac-sigmac) here, the permissible tensile stress of sigmaaciCFRP, the centrifugal stress committed to sigmac;CFRP, and a tc;CFRP ring, and tm; it is the thickness of a permanent magnet ring. According to it, although this numerical example is shown in the Takahashi ** "the development example of a ultra high-speed motor", and the Heisei 8 electrical-and-electric-equipment national conference S.18-3, it is Rota peripheral-speed 196 m/s, and about, sigmam is 2 and 29.2kg [/mm] sigmac [7.8kg / /] is / mm / 2. If 8kg /of 2 and safety are now seen for sigmaam mm and 50kg /of sigmaac(s) is set to 2 mm, tc/tm will drop from (several 1) to about 1/2. That is, even if it has surpassed centrifugal tension sigmaam=8kg/mm2 which work to a permanent magnet, by twisting CFRP of about tc/tm=1/2 thickness, the conditions of sigmac(=7.8kg/mm2) <thetaac (=50kg/mm2) are satisfied, and destruction of a permanent magnet is prevented.
[0004] As conventional technology in which such a permanent magnet formula rotator is another, there are some which were indicated by JP,3-11951,A, JP,7-284237,A, etc. In the "rotator of rotation electrical machinery" shown in former JP,3-11951,A, the structure which inserted the ceramic ring of high tension in the periphery of the permanent magnet attached in the shaft of Rota in the shape of a ring, and inserted the ring of a titanium alloy in the periphery further is proposed. Moreover, in the

"rotator with a permanent magnet of a motor" shown in JP,7-28423,A, the structure which attached the periphery of the permanent magnet attached in the shaft of Rota in the shape of a ring by eye a press fit by the small member of the shape of a ring constituted from non-magnetic material is proposed. Furthermore, the above-mentioned ring-like member is left in accordance with the shaft orientations of Rota, and are arranged. [two or more]

[0005]

[Problem(s) to be Solved by the Invention] The amount of distortion radial [in the case of the above-mentioned conventional example of drawing 3] will be set to 0.00078 if 10000kg /of modulus of direct elasticity of CFRP is set to 2 mm. Therefore, if it is Rota with a diameter of 100mm, the amount of elongation radial [the] will be set to 0.078mm. On the other hand, although it is equivalent to abbreviation 35000r.p.m when this Rota is rotated by peripheral-speed 196 m/s, when rotating Rota at the high speed of tens of thousands of or more revolutions in this way, there is a possibility of causing the Rota vibration resulting from the elongation of the above CFRPs.

[0006] Moreover, according to above-mentioned JP,3-11951,A, since the elastic modulus of a ceramic ring is very large, a permanent magnet is extended to radial with a centrifugal force, and does not cause vibration etc. Moreover, according to JP,7-284237,A, eye a press fit of a ring-like member has protected elongation radial [at the time of high-speed rotation] too. however, no such technology is the sides which have prevented deformation of a permanent magnet and are bound tight in the form which binds a permanent magnet tight, i.e., the thing which attached by carrying out so that a ceramic ring and the ring-like member itself might be directly bound tight to a rotor shaft (shaft) Moreover, assembly etc. uses a ceramic ring intricately with enlargement of a motor.

[0007] The purpose of this invention is that can maintain highly the coaxiality of the ring for a permanent magnet ring and reinforcement, and a motor shaft, and the assembly also offers the permanent magnet formula synchronous motor and rotator of easy structure at the time of high-speed operation rotation.

[0008]

[Means for Solving the Problem]

MEANS

[Means for Solving the Problem] Two or more ring-like permanent magnets with which arranged this invention in the shaft orientations of a shaft and this shaft, and it was equipped in order to attain the above-mentioned purpose, Direct system **** which can give the initial interference corresponding to this ring-like permanent magnet and the centrifugal stretching of itself, and makes a part of the inside is united with the aforementioned shaft a direct system. And the rotator of the motor characterized by having the titanium ring with which insides other than the aforementioned direct system **** were united with this peripheral surface of the aforementioned ring-like permanent magnet the system is indicated.
[0009]
[Embodiments of the Invention] Hereafter, the gestalt of operation of this invention is explained. The cross section and drawing 2 which show the composition of the rotator of the permanent magnet formula synchronous motor with which drawing 1 becomes this invention are the A-A cross section of drawing 1 . In these drawings, a rotator consists of a shaft 1, a permanent magnet ring 2, and a titanium ring 3, and the stator 16 is equipped with the coil 17. Although two or more permanent magnet rings 2 are arranged at shaft orientations and some intervals are prepared between each ring, it divides into two or more rings in this way because it becomes impossible to create the permanent magnet ring of big width of face when a motor becomes to some extent large. The titanium ring 3 is also divided into plurality, and it is equipped so that the permanent magnet ring 2 may be held. Projected part 3A is prepared in the inner circumference of each titanium ring 3, the projected part 3A has been arranged between the permanent magnet rings 2, and the inner circumference section of projected part 3A is united with the front face of a shaft 1 the system. Although it is a ring-like like drawing 2 , the cross-section configuration of the permanent magnet ring 2 is magnetized so that N and the magnetic pole of one pair of south pole may be formed at least magnetically.
[0010] In the above-mentioned composition, the bore of the inner circumference section of height 3A of the titanium ring 3, i.e., system **** on the front face of a shaft, and the relation of a shaft outer-diameter size shall give the initial interference (initial bolting force) corresponding to the centrifugal-force elongation also in consideration of the centrifugal force of a permanent magnet 2. This interference can be expressed with an outline degree type.
[Equation 2] epsilon>=(Em-tm/Et-tt) epsilonm+epsilont deltad=epsilonD -- here -- the modulus of direct elasticity of Em; permanent magnet ring, the modulus of direct elasticity of Et; titanium ring, and epsilonm; -- the virtual distortion by the centrifugal force of a permanent magnet ring, the centrifugal distortion of an epsilont; titanium ring, the diameter of D; titanium ring, the initial interference of a deltad; titanium ring, the thickness of tm; permanent magnet ring, and tt are the thickness of a titanium ring The first term of the right-hand side of (several 2) is equivalent to the interference for taking charge of the centrifugal force committed to the permanent magnet ring 2, and the second term of the right-hand side is equivalent to the interference for taking charge of the centrifugal-force elongation of titanium ring 3 self. By giving the initial bolting force more than both sum, it is lost that the titanium ring 3 separates from a shaft 1 during rotation. And since it is restrained by radial by setting the permanent magnet ring 2 by the titanium ring 3 a system, coaxiality with a shaft 1 is maintained. Since the coaxiality of the titanium ring 3 on stream and a shaft 1 can be maintained by doing in this way, imbalanced generating on stream can be lost.

[0011] If one permanent magnet ring 2 is inserted in on a shaft 1 in the assembly of the rotator of drawing 1 , next, one titanium ring 3 will be inserted in. ** which the inner skin between the permanent magnet ring previously inserted in at this time and one end of the height of a titanium ring puts together a system, and height inner skin unites with a shaft a system -- like, the aforementioned initial interference **d is given and a titanium ring is inserted in next, ** which the following permanent magnet ring unites with the inner skin between the height of the titanium ring inserted in now, and another edge a system -- the permanent magnet ring concerned is inserted in like Although a permanent magnet and a titanium ring can be attached in a rotator by repeating the same work as the following, in order to do easy that a permanent magnet ring has small **** critical stress and the inclusion work of the titanium ring at the time of baked BAME work, and a permanent magnet ring and to perform them quickly at this time, the initial interference to the shaft of a permanent magnet ring works as needlessness, 0 [i.e.,].

[0012] According to the form of this operation, since sufficient interference for a direct shaft front face is given and a titanium ring is made to set a system by the height of the inner skin, by not extending the titanium ring itself to radial with a centrifugal force at the time of high-speed rotation, and also system-setting a permanent magnet by the titanium ring, and holding it, it also prevents being extended with a centrifugal force and it can oppress vibration of high-speed operation certainly.

[0013] Drawing 4 shows another example of composition of the rotator with a permanent magnet which becomes this invention, and changes the configuration of a titanium ring. This drawing is a cross section which includes the shaft of a rotator as well as drawing 1 , and is illustrating a part of the upper half. Although it is the same as the composition of drawing 1 that the permanent magnet ring 2 has in the periphery of a shaft 1 at a suitable interval, and are attached in it, the titanium ring 40 is making the L type configuration to so to speak the thing of drawing 1 having been T type, if it sees in the cross section of this drawing. [two or more] namely, ** which height 40A is prepared in the inner circumference section of the end of a ring, and this is inserted between permanent magnet rings, and is united with a shaft 1 a direct system -- it is like There is the same effect as drawing 1 by setting it as the value which explained the path of the inner skin of height 40A by (several 2), and giving a suitable interference also with this composition. Furthermore, in the case of drawing 4 , molding of the titanium ring 40 becomes easy, and installation to a shaft can also be more easily performed now.

[0014] Drawing 5 shows still more nearly another example of composition of the rotator with a permanent magnet which becomes this invention, and is the modification of the composition of drawing 1 . That is, four pieces adjoin shaft orientations at a time, it is arranged, height 50A of the titanium ring 50 of a T character type [cross section / the] is inserted among every four pieces, and a permanent magnet 2 is ****** put together a system with the front face of a shaft 1 in the inner skin. It is also possible to take as arbitrarily as 2, 3, and ... the number of the permanent magnet by which contiguity arrangement is carried out, the shaft-orientations width of face of a titanium ring becomes long, so that many this is taken, and such composition has an effect in reduction of the installation routing to a shaft. However, increase of shaft-orientations width of face causes increase of the eddy current loss within titanium, and the area of direct system **** with a shaft decreases. Therefore, it is necessary to select the number of a suitable permanent magnet by these trade-ofves.

[0015] Drawing 6 shows still more nearly another example of composition of the rotator with a permanent magnet which becomes this invention, and is the modification of the composition of drawing 4 . That is, four pieces adjoin shaft orientations at a time, it is arranged, height 60A of the titanium ring 60 of a L character type [cross section / the] is inserted among every four pieces, and a permanent magnet 2 is ****** put together a system with the front face of a shaft 1 in the inner skin. The fitter to a shaft can cut down by choosing suitably the number of the permanent magnet by which contiguity arrangement is carried out also in this case. Moreover, in any [drawing 5 and / of 6] case, the big bending moment starts the root of a height by the permanent magnet at the time of high-speed rotation, and the centrifugal stretching of the titanium ring itself. Since the bending moment becomes so large that the shaft-orientations width of face of a titanium ring is large, it needs the design also in consideration of this point.

[Translation done.]

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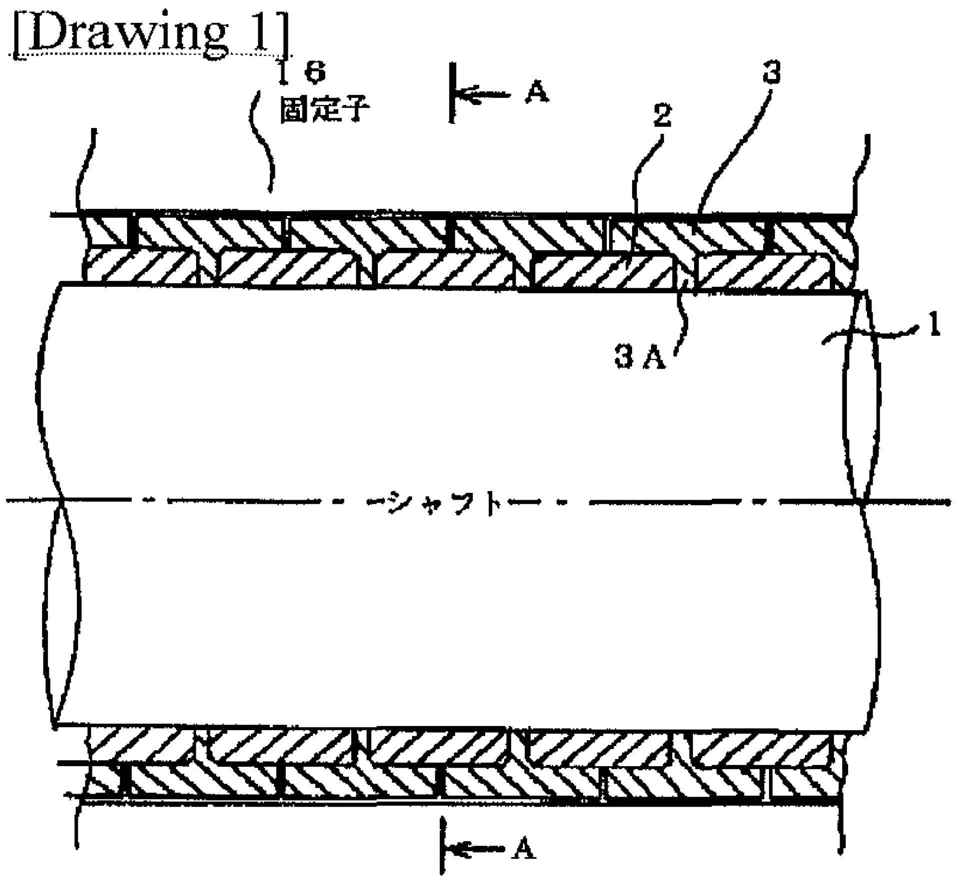
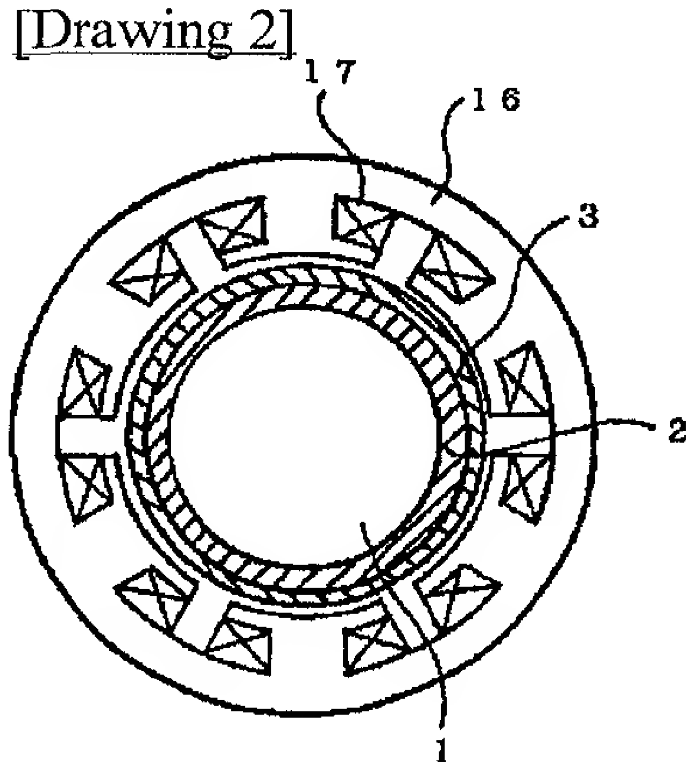
DRAWINGS

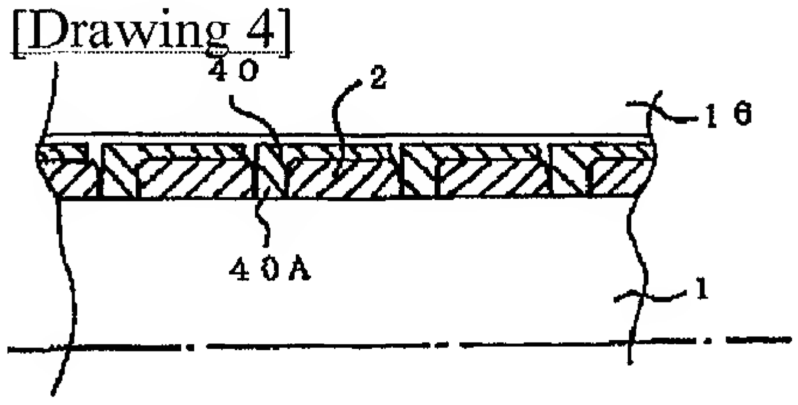
[Drawing 1]



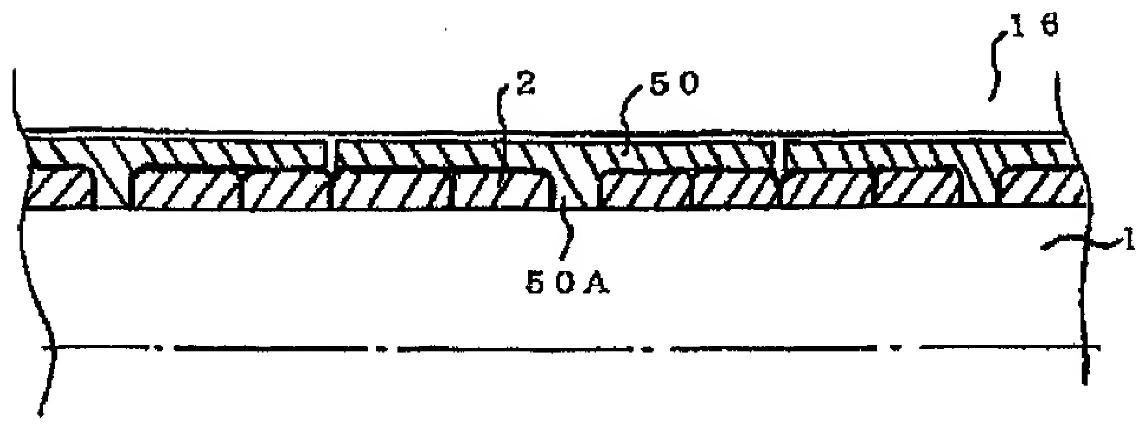
[Drawing 2]



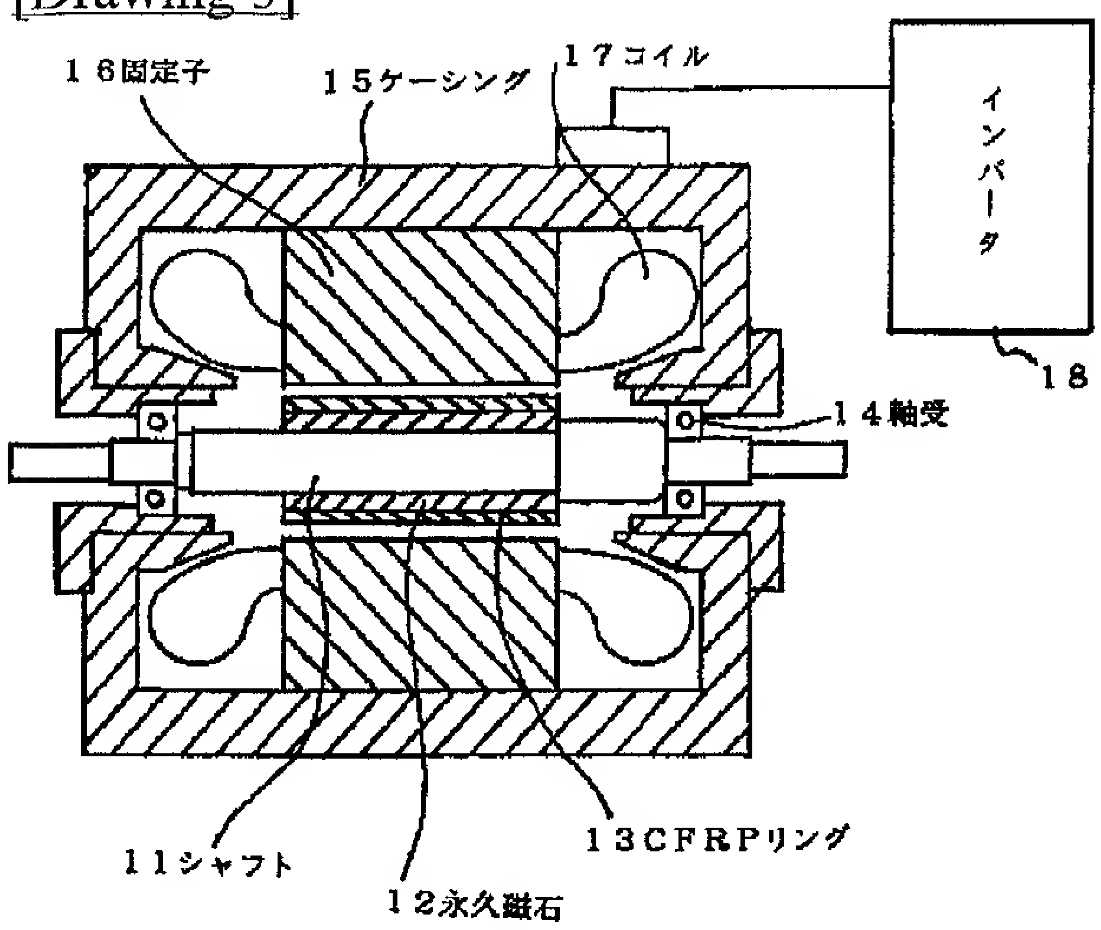
[Drawing 4]



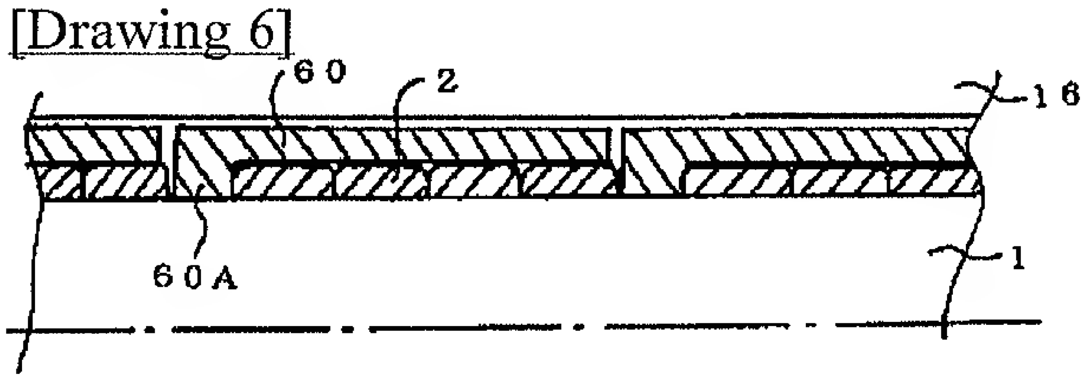
[Drawing 5]



[Drawing 3]



[Drawing 6]



[Translation done.]

PTO 03-203

Japanese Kokai Patent Application
No. Hei 10[1998]-243586

PERMANENT MAGNET TYPE SYNCHRONOUS MOTOR AND ROTOR THEREOF

Haruo Miura et al.

UNITED STATES PATENT AND TRADEMARK OFFICE
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Examination Request:	Not filed

PERMANENT-MAGNET SYNCHRONOUS MOTOR AND ROTOR

[Eikyu jisekishiki doki dendoki to sono kaitenshi]

Inventors:	Haruo Miura et al.
Applicant:	000005108 Hitachi, Ltd.

[There are no amendments to this patent.]

Claims

1. A motor rotor characterized by the fact that it is composed of the following parts:

a shaft,

multiple annular permanent magnets installed side by side in the axial direction of said shaft,

and titanium rings, which provide the initial holding force for matching the centrifugal force and elongation of the annular permanent magnets, have a direct engagement surface that forms a portion of its inner surface and directly engage with said shaft, and have an inner surface

other than said direct engagement surface and engage with the outer peripheral surface of said annular permanent magnets.

2. The motor rotor described in Claim 1 characterized by the fact that the direct engagement surface of said titanium rings is the surface formed by the ends of the projections on the inner peripheral surface set in the central portion in the axial direction of said titanium ring.

3. The motor rotor described in Claim 1 characterized by the fact that the direct engagement surface of said titanium rings is the surface formed by ends of the projections on the inner peripheral surface arranged on one end in the axial direction of said titanium ring.

4. A permanent-magnet synchronous motor characterized by the fact that it utilizes the motor rotor described in any one of Claims 1-3.

Detailed explanation of the invention

[0001]

Technical field of the invention

The present invention pertains to a permanent-magnet synchronous motor for use as an ultra-high-speed variable-speed motor for driving a compressor, etc., as well as its rotor.

[0002]

Prior art

Motors with permanent magnets attached to the rotor are widely used as miniature high-performance DC or AC servo-motors in many fields. Figure 3 is a diagram illustrating an example of the conventional structure of a permanent-magnet synchronous motor equipped with a rotor having annular permanent magnets. As shown in this figure, annular permanent magnets

(12) are installed on shaft (11) of the motor, and carbon-fiber [reinforced plastic] (hereinafter referred to as CFRP) is wound thereon to form CFRP ring (13) as the motor rotor. The rotor is supported on bearings (14) in housing (15). Stator (16) with coil (17) accommodated therein is held in housing (15). Power is fed to this motor by means of inverter (18).

[0003]

For the permanent magnet type synchronous motor in this example, it is possible to reduce the size of the rotor, and there is no need to use excitation current. Consequently, the efficiency is improved, which is advantageous. In order to ensure a high magnetic flux density, neodymium permanent magnets, etc. are used. For permanent magnets (12). However, for such magnet material, the breaking tension σam is as low as about 8 kg/mm^2. Consequently, it is reinforced by winding CFRP (13) with a high specific strength. Although the tensile strength of the carbon fibers themselves is at least 200 kg/mm^2, in practice, because the fiber orientation does not agree with the direction of the centrifugal force and because epoxy resin is impregnated, when CFRP is installed on the rotor, the tensile strength is tens of kg/mm^2 or higher. In this case, the reinforcement effect of CFRP is represented by the following equation:

[Equation 1] $$tc = (\sigma m - \sigma am)\ tm/(\sigma ac - \sigma c)$$

where σm represents the centrifugal tension acting on the permanent magnet, σam represents the tolerable tensile strength of the permanent magnet, σaci represents the tolerable tension, σc represents the centrifugal stress acting on CFRP, tc represents the thickness of CFRP, and tm represents the thickness of the permanent magnet ring. The above listed numerical example is

described in the following reference: K. Takahashi: "Case of development of ultrahigh-speed motor," 1996 National Conference of Electrical Association, S.18-3. In this case, the circumferential velocity of the rotor is 196 m/s, σm is 29.2 kg/mm^2, and σc is 7.8 kg/mm^2. If σam is 8 kg/mm^2, and for safey's sake, σac is 50 kg/mm^2, then according to Equation 1, tc/tm is about 1/2. That is, even when the centrifugal tension σam acting on the permanent magnet is over 8 kg/mm^2, by winding CFRP with a thickness corresponding to tc/tm of about 1/2, the condition of σc (=7.8 kg/mm^2) < θac (=50 kg/mm^2) is met, and damage to the permanent magnet can be prevented.

[0004]

Japanese Kokai Patent Application Nos. Hei 3[1991]-11951 and Hei 7[1995]-284237 described other methods of the prior art of the permanent-magnet-rotor. Japanese Kokai Patent Application No. Hei 3[1991]-11951 describes "rotor of rotating motor" characterized by the following structure: ceramic rings with high tensile strength are fitted for fastening on the outer periphery of permanent magnets mounted in ring configuration on the shaft of the rotor, and rings made of a titanium alloy are fitted on the outer periphery of said ceramic rings, respectively. Japanese Kokai Patent Application No. Hei 7[1995]-28423 describes a "rotor with permanent-magnet motor" characterized by the following structure: on the outer periphery of permanent magnets attached as rings on the shaft of the rotor, and annular, narrow elements made of a nonmagnetic material are fitted for fastening on the outer periphery of the permanent magnets. Multiple said annular elements are separately arranged along the axial direction of the rotor.

[0005]

Problems to be solved by the invention

In the prior art shown in Figure 3, if the longitudinal modulus of CFRP is 10,000 kg/mm^2, then the amount of deformation in the radial direction is 0.00078. Consequently, for a rotor with a diameter of 100 mm, the extension in the radial direction is 0.078 mm. If the rotor rotates with a circumferential velocity of 196 m/s, this corresponds to a velocity of about 35,000 rpm. However, if the velocity goes as high as tens of thousand of rpm, rotor vibration may occur due to said extension of CFRP.

[0006]

According to said Japanese Kokai Patent Application No. Hei 3[1991]-11951, because the ceramic rings have a very high modulus, no extension and vibration in the radial direction due to centrifugal force takes place for the permanent magnets. According to said Japanese Kokai Patent Application No. Hei 7[1995]-284237, due to the fitting of annular elements, elongation in the radial direction can be prevented when the rotor rotates at a high velocity. However, all of the aforementioned examples from the prior arts are designed for prevent deformation of permanent magnets by using the form of fastening of the permanent magnets and their fastening elements, that is, ceramic rings and annular elements, are themselves not directly mounted and fastened on the rotor axle (shaft). Also, since ceramic rings are used, the size of the motor becomes larger, and assembly becomes complicated.

[0007]

The purpose of the present invention is to provide a permanent-magnet synchronous motor and its rotor with a structure that can maintain a high coaxiality of the permanent magnet rings, reinforcing rings and motor shaft, and that allows easy assembly.

[0008]

Means to solve the problems

The purpose of the present invention is to solve the aforementioned problems of the conventional methods by providing a motor rotor characterized by the fact that it is composed of the following parts: a shaft, multiple annular permanent magnets installed side by side in the axial direction of said shaft, and titanium rings, which provide the initial holding force for matching the centrifugal force and elongation of the annular permanent magnets, have a direct engagement surface that forms a portion of its inner surface and directly engage with said shaft, and have an inner surface other than said direct engagement surface and engage with the outer peripheral surface of said annular permanent magnets.

[0009]

Embodiments of the invention

In the following, embodiments of the present invention will be examined. Figure 1 is a cross-sectional view illustrating the structure of the rotor of the permanent-magnet synchronous motor of the present invention. Figure 2 is a cross-sectional view along A-A in Figure 1. In these figures, the rotor is composed of shaft (1), permanent magnet rings (2), and titanium rings (3). Also, coil (17) is mounted on stator (16). Multiple permanent magnet rings (2) are set in the axial

direction, with a small gap between neighboring rings. Division of said multiple rings is required because when the motor becomes larger than a prescribed size, it becomes impossible to manufacture a single permanent magnet ring with a large width. Also, multiple titanium rings (3) are divided from each other and are mounted to hold said permanent magnet rings (2). Projection (3A) is formed on the inner periphery of each titanium ring (3). Said projection (3A) is located between permanent magnet rings (2), with the inner peripheral surface of projection (3A) engage with the surface of shaft (1). As shown in Figure 2, the cross-sectional shape of permanent magnet ring (2) is annular, and it is magnetized to form at least one pair of N and S poles.

[0010]

In the aforementioned application example, the inner dimensions of the inner peripheral portion of projections (3A) of titanium rings (3), that is, the part that engages with the surface of the shaft, and the outer diameter of the shaft should have an appropriate relationship to provide an initial interference (initial holding force) that matches the centrifugal extension in consideration of the centrifugal force of permanent magnet rings (2). This interference can be represented by the following relationship:

[Equation 2] $$\varepsilon \geq (Em \bullet tm/Et \bullet tt)\, \varepsilon m + \varepsilon t$$

where Em represents the longitudinal modulus of the permanent magnet rings, Et represents the longitudinal modulus of the titanium rings, εm represents the virtual deformation of the permanent magnet rings under the centrifugal force, εt represents the distortion of the titanium rings under the centrifugal force, D represents the diameter of the titanium rings, Δd represents

the initial interference of the titanium rings, tm represents the thickness of the permanent magnet rings, and tt represents the thickness of the titanium rings. The first term on the right-hand side of (Equation 2) corresponds to the interference for receiving the centrifugal force acting on permanent magnet rings (2). The second term on the right-hand side corresponds to the interference for receiving the extension of titanium rings (3) themselves. When an initial fastening force higher than the sum of said two items is applied, titanium rings (3) do not leave shaft (1) during rotation. Also, since permanent magnet rings (2) are engaged with titanium rings (3), they are restrained in the radial direction. Consequently, their coaxiality with shaft (1) can be maintained. In this way, it is possible to maintain good coaxiality between titanium rings (3) and shaft (1) during operation. As a result, there is no imbalance during operation.

[0011]

When the rotor shown in Figure 1 is assembled, first, one permanent magnet ring (2) is fitted on shaft (1). Then, one titanium ring (3) is fitted. At this time, the titanium ring that gives said initial interference Δd is fitted so that the first permanent magnet ring engage with the inner peripheral surface between itself and one end of the projection on the titanium ring, and the inner peripheral surface of the projection is engaged with the shaft. Then, the next permanent magnet ring is fitted such that it engage with the inner peripheral surface between itself and the other end portion of the projection on the titanium ring that has been fitted. Then, the same operation is carried out repeatedly until all of the permanent magnet rings and titanium rings are mounted on the rotor. In this case, the operation is performed with zero initial interference of the permanent magnet rings on the shaft so as to reduce the tensile limit stress for the permanent magnet rings,

to facilitate the operation for assembling the titanium rings and the permanent magnet rings in the shrink-fitting operation and to ensure that the operation can be carried out quickly.

[0012]

In this embodiment, because the titanium rings directly engage with the surface of the shaft by means of the projections on the inner peripheral surface with sufficient interference, the titanium rings themselves do no extend in the radial direction under the centrifugal force when rotating at high speed, and as the permanent magnets are also held as they are engaged by the titanium rings, their extension under centrifugal force can also be prevented, and vibration in high-speed operation can be suppressed reliably.

[0013]

Figure 4 is a diagram illustrating another application example of the rotor equipped with permanent magnets in the present invention. In this case, the shape of the titanium rings is changed. This figure is a cross-sectional view that includes the shaft of the rotor is the same as that in Figure 1. Also, it only shows a portion of the upper half. Permanent magnet rings (2) are mounted with appropriate gaps on the outer periphery of shaft (1). This is identical to the structure shown in Figure 1. However, the cross-sectional shape of titanium rings (40) is L-shaped instead T-shaped, as shown in Figure 1. That is, projection (40A) is formed on the inner peripheral portion on one end of the ring, and it is inserted between neighboring permanent magnet rings, and directly engages with shaft (1). In this constitution, the diameter of the inner peripheral surface of projection (40A) is also selected to have the value defined by Equation 2 so as to provide appropriate interference. As a result, the same effect as that shown in Figure 1 can

be exhibited. In addition, for the constitution shown in Figure 4, molding of titanium rings (40) is easier, and their mounting on the shaft can also be carried out simply.

[0014]

Figure 5 is a diagram illustrating another application example of the rotor equipped with permanent magnets in the present invention. It is a variant of that shown in Figure 1. In this example, four permanent magnets (2) are set adjacent to each other as a group in the axial direction. Projection (50A) of titanium ring (50) with T cross-sectional shape is inserted between neighboring 4-permanent magnet groups, and its inner surface engages with the surface of shaft (1). Here, there may be any number (2, 3,...) of permanent magnets set adjacent to each other in a group. The larger the number of permanent magnets in each group, the longer the titanium ring in the axial direction, and the less the number of man-hours required to, install them on the shaft. However, an increase in the length in the axial direction leads to an increase in the eddy currents in titanium, and a decrease in the surface area for direct engagement to the shaft. Consequently, it is necessary to select an appropriate number of the permanent magnets in each group in consideration of an appropriate tradeoff.

[0015]

Figure 6 is a diagram illustrating another example of the constitution of the rotor equipped with permanent magnets in the present invention. It is a variant of that shown in Figure 4. In this application example, four permanent magnets (2) are set adjacent to each other to form a group in the axial direction. Projection (60A) of titanium ring (60) with L-sectional is inserted between neighboring 4-permanent magnet groups, and its inner surface engage with the surface

of shaft (1). In this constitution, one also selects an appropriate number of permanent magnets to be set adjacent to each other in a group; as a result, it is possible to reduce the number of man-hours for installation on the shaft. Also, in either Figure 5 or Figure 6, a significant bending moment is applied to the mounting portion of each projection due to the elongation caused by the centrifugal force of the permanent magnets and titanium rings themselves during high rotational velocity. The increase in the bending moment with the width of the titanium ring in the axial direction should be taken into consideration in the design process.

[0016]

Effects of the invention

According to the present invention, no rotor imbalance during high-speed operation. Consequently, it is possible to suppress vibrations during operation and to maintain stability under the centrifugal force acting on the permanent magnets. As a result, it is possible to realize operation with high stability and reliability.

Brief description of the figures

Figure 1 is a diagram illustrating an example of the constitution of the rotor equipped with permanent magnets in the present invention.

Figure 2 is a cross-sectional view taken across A-A in Figure 1.

Figure 3 is a diagram illustrating an example of constitution of the conventional permanent-magnet synchronous motor.

Figure 4 is a diagram illustrating another example of the constitution of the rotor equipped with permanent magnets in the present invention.

Figure 5 is a diagram illustrating yet another example of the constitution of the rotor equipped with permanent magnets in the present invention.

Figure 6 is a diagram illustrating yet another example of the constitution of the rotor equipped with permanent magnets in the present invention.

Brief description of the part numbers

1	Shaft
2	Permanent magnet ring
3, 40, 50, 60	Titanium ring
3A, 40A, 50A, 60A	Projection
16	Iron core of stator
17	Coil

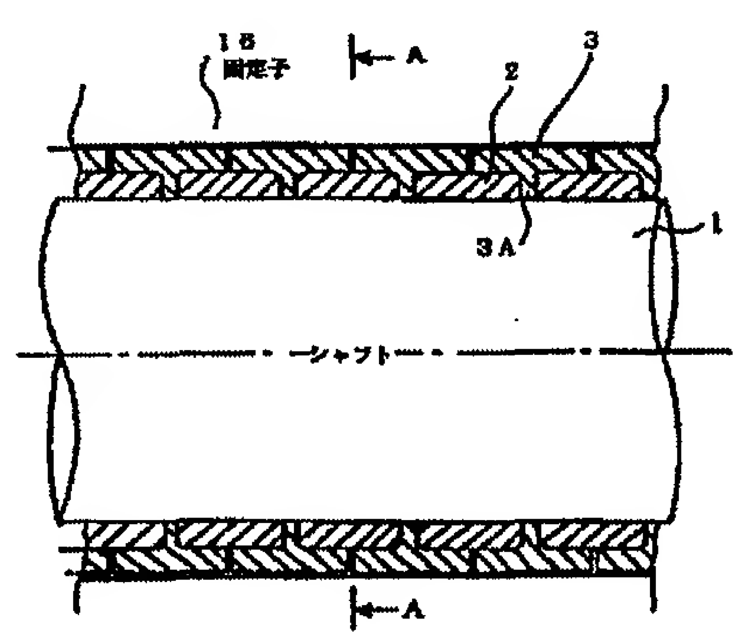

Figure 1

Key: 16 Stator

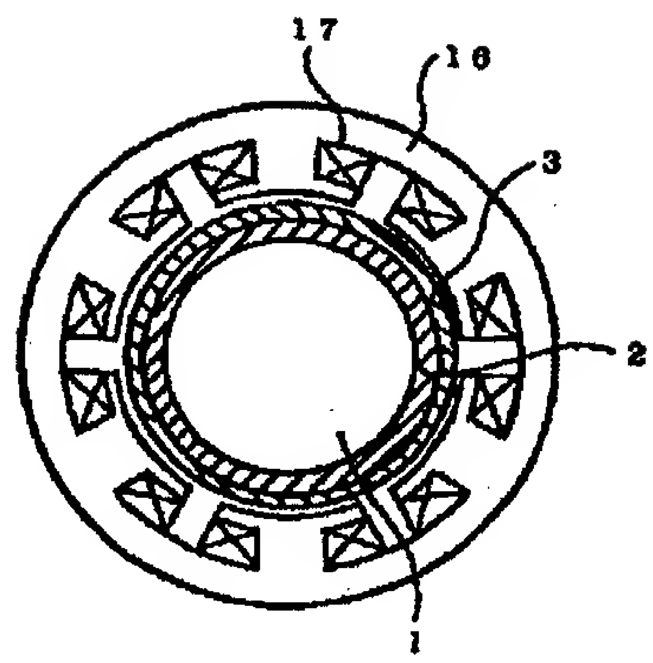

Figure 2

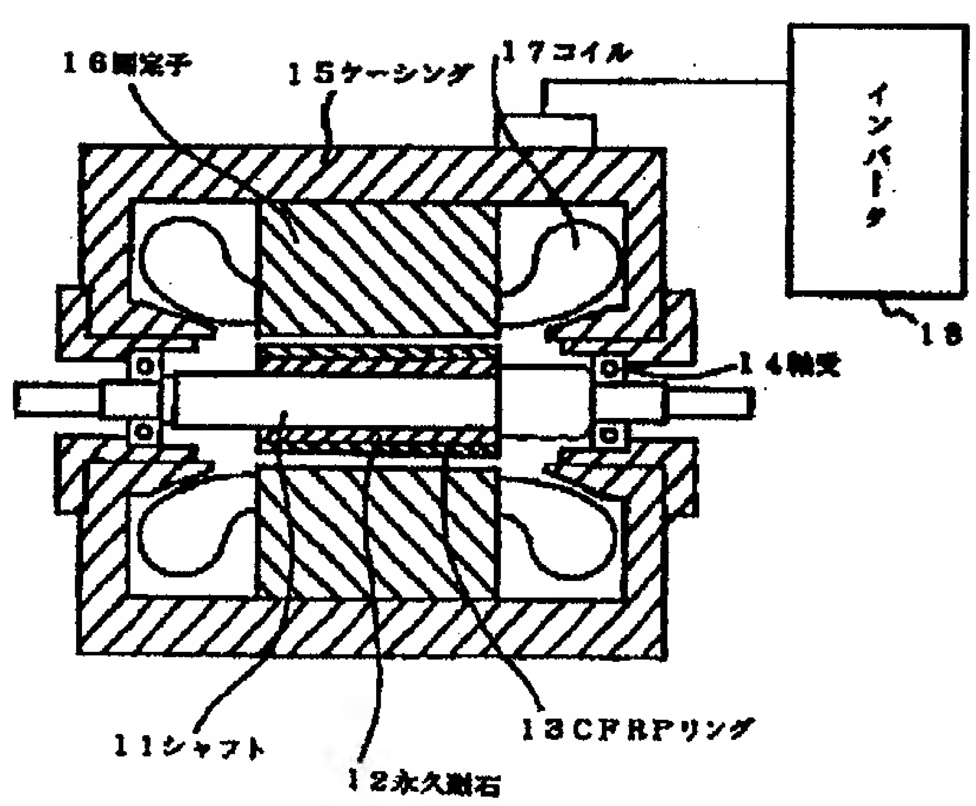

Figure 3

Key:	11	Shaft
	12	Permanent magnet
	13	CFRP ring
	14	Bearing
	15	Casing

16 Stator

17 Coil

18 Inverter

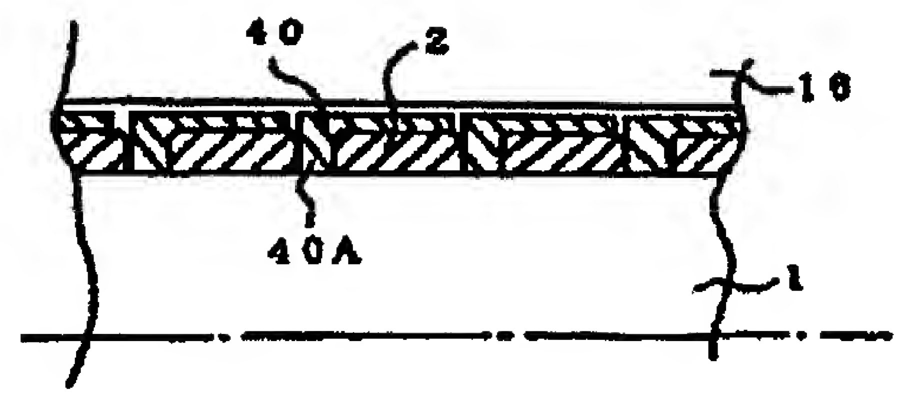

Figure 4

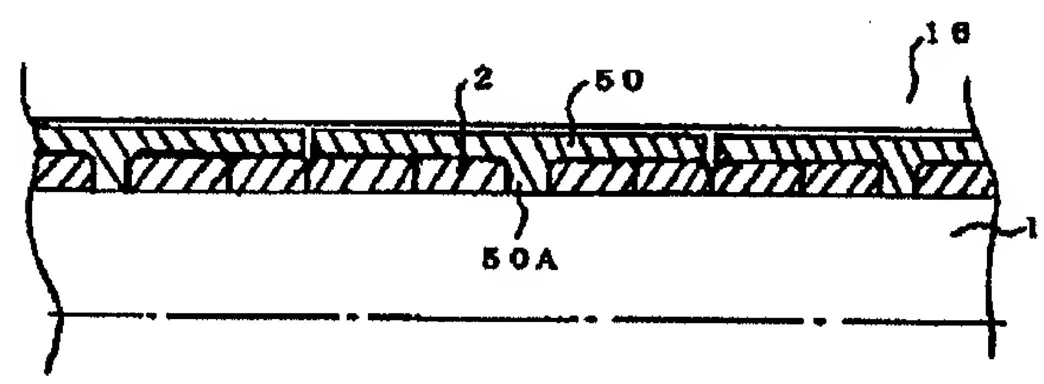

Figure 5

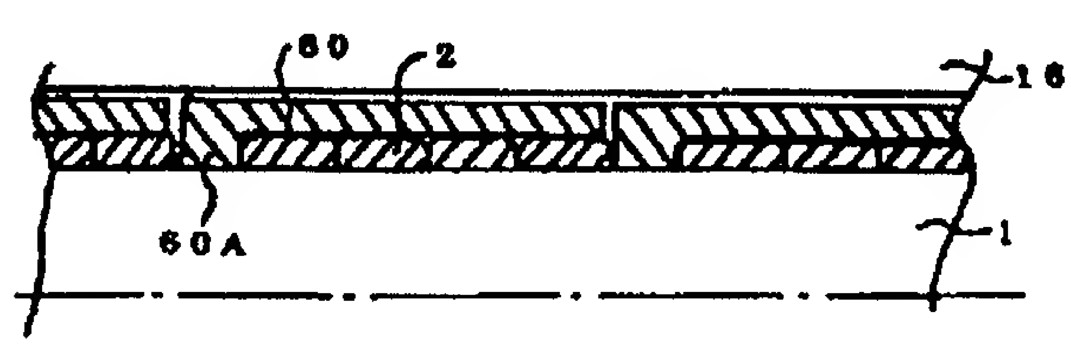

Figure 6